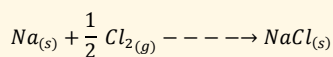


**Enthalpy Change ( $\Delta H$ )** : is the heat change at constant pressure. Usually quoted in KJ/mol.

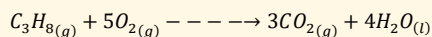
<p><b>Exothermic Reaction</b></p>	<p><math>\Delta H = -ve</math></p>	<p>Releases heat energy from system to surroundings. Temperature of surroundings increases.</p>	<p><math>C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O</math></p>	
<p><b>Endothermic Reaction</b></p>	<p><math>\Delta H = +ve</math></p>	<p>Takes in heat energy from surroundings to system. Temperature of surroundings decreases.</p>	<p><math>CaCO_3 \rightarrow CaO + CO_2</math></p>	

**Key Definitions**

**Standard Enthalpy change of Formation ( $\Delta H_f^\ominus$ )**: is the enthalpy change when **one mole of a substance is formed** from its **constituent elements** under **standard conditions**, with all **reactants and products in their standard states**



**Standard Enthalpy change of Combustion ( $\Delta H_c^\ominus$ )**: is the enthalpy change when **one mole of substance** is **completely burned/combusted in oxygen** under **standard conditions**, with all **reactants and products in their standard states**



Note:

Standard enthalpy of formation of elements is 0 KJ/mol e.g. Mg, O<sub>2</sub>

Standard enthalpy of combustion of Oxygen is 0 KJ/mol.

Standard conditions ( $\ominus$ ) refer to Temperature: 298K, Pressure: 100kPa

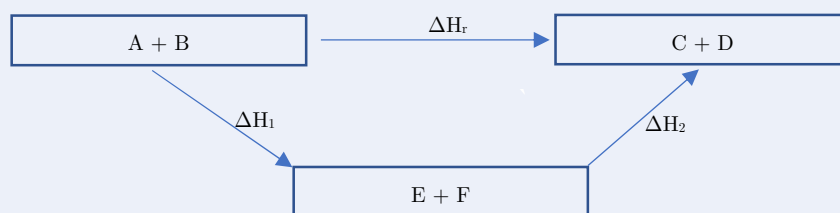
**Calculating Enthalpy change of a reaction**

The enthalpy change of a reaction can be calculated in the following ways where applicable:

- 1) Hess's Law
- 2) Calorimetry
- 3) Mean Bond Enthalpies

**Hess' Law**

Hess's Law states that the enthalpy change of a reaction is independent of the route taken.



$$\Delta H_r = \Delta H_1 + \Delta H_2$$



### Calorimetry

The Enthalpy change of a reaction can also be calculated experimentally via calorimetry. The general equation used to calculate the energy change is:

$$Q = m \times c \times \Delta T$$

Where:

Q= heat change (J)

m= mass of substance being heated or cooled (g)

c = specific heat capacity ( $\text{Jg}^{-1}\text{K}^{-1}$ ): states the energy required to raise the temperature of 1g of a substance by 1K.

$\Delta T$ = temperature change (K)

In order to calculate enthalpy change, recall units are KJ/mol, we divide Q by mol. Ensure to convert Q from Joules to KJ by dividing by 1000.

$$\Delta H = \frac{Q}{n} = \frac{KJ}{mol}$$

### Calculating enthalpy of combustion

A fuel can be burned in order to heat a pre-determined mass of water to calculate the enthalpy change of combustion of the fuel.

#### Example 3

4.6 of Ethanol was completely burned to raise the temperature of 100cm<sup>3</sup> of Water from 20°C to 28°. Calculate the enthalpy change of combustion?

First calculate the heat change:

$$\begin{aligned} Q &= m \times c \times \Delta T \\ Q &= 100 \times 4.18 \times 8 \\ Q &= 3,344 \text{ J} = 3.344 \text{ KJ} \end{aligned}$$

In order to calculate the energy released per mole, we need to calculate the moles of ethanol:

$$n = \frac{\text{mass}(g)}{Mr} = \frac{4.6}{46} = 0.1 \text{ moles}$$

The enthalpy change of combustion in KJ/mol can be calculated as follows:

$$\Delta H = \frac{Q}{n} = \frac{3.344}{0.1} = -33.44 \text{ KJ/mol}$$

Note, a negative sign is included in the answer, as combustion is an exothermic reaction i.e. temperature of the surrounding (water) goes up.

Discrepancies in this method include: incomplete combustion of fuel, heat loss, evaporation of fuel post weighing, non-standard conditions.

### Example 4 - Calculating enthalpy change of neutralisation reactions

30cm<sup>3</sup> of 0.6mol/dm<sup>3</sup> HCl was added to 20cm<sup>3</sup> of 0.5mol/dm<sup>3</sup> of KOH. The temperature of the solution increased from 20°C to 27.2°C. Calculate the enthalpy change of the reaction:

First calculate the heat change:

$$\begin{aligned} Q &= m \times c \times \Delta T \\ Q &= 50 \times 4.18 \times 7.2 \\ Q &= 1,504.8 \text{ J} = 1.5048 \text{ KJ} \end{aligned}$$

In order to calculate the energy released per mole, we need to calculate the moles of HCl and KOH, to identify which is the limiting reactant.

$$\text{moles of HCl} = \frac{c \times V(\text{cm}^3)}{1000} = \frac{0.6 \times 30}{1000} = 0.018 \text{ moles}$$

$$\text{moles of KOH} = \frac{c \times V(\text{cm}^3)}{1000} = \frac{0.5 \times 20}{1000} = 0.010 \text{ moles}$$

Note only the limiting reactant contributes to the energy change, the excess mol do not react hence do not contribute to energy change. Therefore, the limiting reactant moles should be used. Note temperature of the solution increases, hence exothermic:

$$\Delta H = \frac{Q}{n} = \frac{1.5048}{0.01} = -150.48 \text{ KJ/mol}$$

### Example 5- Calculating enthalpy change of displacement reactions

5g of Zn is added to 25cm<sup>3</sup> of 0.6 mol/dm<sup>3</sup> CuSO<sub>4</sub> soln. The temperature of the solution increases by 5.5K. Calculate the enthalpy change of the reaction?

First calculate the heat change:

$$\begin{aligned} Q &= m \times c \times \Delta T \\ Q &= 25 \times 4.18 \times 5.5 = 574.5 \text{ J} = 0.575 \text{ KJ} \end{aligned}$$

In order to calculate the energy released per mole, we need to calculate the moles of Zn and CuSO<sub>4</sub>, to identify which is the limiting reactant.

$$\text{moles of Zn} = \frac{\text{mass}(g)}{Ar} = \frac{5}{65.4} = 0.0765 \text{ moles}$$

$$\text{moles of CuSO}_4 = \frac{c \times V(\text{cm}^3)}{1000} = \frac{0.6 \times 25}{1000} = 0.015 \text{ moles}$$

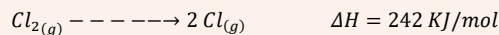
Note only the limiting reactant contributes to the energy change, the excess mol do not react hence do not contribute to energy change. Therefore, the limiting reactant moles should be used:

$$\Delta H = \frac{Q}{n} = \frac{0.575}{0.015} = -38.3 \text{ KJ/mol}$$

### Bond Enthalpies

**Bond Dissociation Enthalpy** : is the enthalpy change required to break one mol of a covalent bond with all species in their gaseous state.

**Mean Bond Enthalpy** : average value of the bond dissociation enthalpy for a given bond taken from a range of different compounds.



Note: Bond enthalpy values are always positive, as energy is required to break the bond. Bond Breaking= endothermic. Bond forming= exothermic.

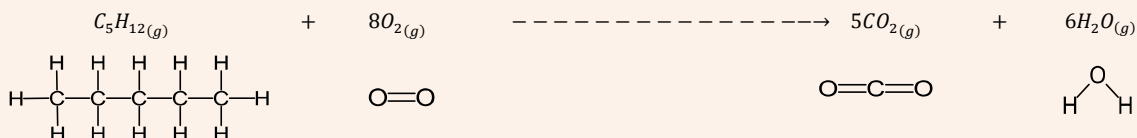
To calculate enthalpy change of a reaction using bond enthalpies, use the below formulae:

$$\Delta H = \sum \text{Bonds energies of bonds broken} - \sum \text{Bonds energies of bonds formed}$$

### Example 6

Calculate the enthalpy change of combustion of Pentane using the data table provided below?

Bond	C-C	C-H	O=O	C=O	O-H
Mean Bond Enthalpy KJ/mol	347	412	497	744	463



C-H : 12 x 412= 4,944	C=O : 5 x 2 x 744= 7,440
C-C : 4 x 347= 1,388	O-H : 6 x 2 x 463= 5,556
O=O : 8 x 497= 3,976	
=10,308	=12,996

$$\Delta H = \sum \text{Bonds energies of bonds broken} - \sum \text{Bonds energies of bonds formed}$$

$$\Delta H = 10,308 - 12,996 = -2,688 \text{ KJ/mol}$$

Note: Drawing a displayed formula of the reactants and products helps with visualisation of the no. of bonds present in the respective reactants and products. Highly recommend this.